Physical limitations of signal conversion

Why this matters for CSE Students

- Understanding the physical limitations of signal conversion is crucial for "Power Budgeting."
- If the light signal becomes too weak due to fiber loss,
  - the photocurrent will drop below the noise floor, leading to a high Bit Error Rate (BER).

Concept:

- In an optical communication system, the receiver's job is to convert light (photons) back into electricity (electrons).
  - Quantum Efficiency (η): This represents the "success rate" of the photodiode. A 70% efficiency means that for every 100 photons that hit the detector, only 70 successfully generate an electron-hole pair to create current.
  - Responsivity (R): This is a practical measure for engineers.
    - While quantum efficiency is a ratio of particles, Responsivity tells us exactly how many Amperes of current we get for every Watt of light power.
    - It is wavelength-dependent because the energy of a photon changes with its color (wavelength).

Concept:

- Photocurrent (I_p): This is the actual electrical signal that will be amplified and processed by the rest of the computer system to recover the transmitted data.

Exercise: Optical Detector Performance

Question:

An optical receiver uses a photodiode with a quantum efficiency of **70%** at a wavelength of **1310 nm**.

1. Calculate the **Responsivity (R)** of the photodiode. (2 Marks)
2. If the received optical power is **5 μW**, calculate the resulting **photocurrent (I_p)**. (2 Marks)

Solution

1. Calculating Responsivity (R):

The formula for Responsivity is:

$$R = \frac{\eta q}{h\nu} = \frac{\eta q \lambda}{hc}$$

Where:

- η (Quantum Efficiency) = 0.70
- q (Electron charge) $\approx 1.6 \times 10^{-19}\ \text{C}$
- λ (Wavelength) = $1310 \times 10^{-9}\ \text{m}$
- h (Planck's constant) $\approx 6.626 \times 10^{-34}\ \text{J} \cdot \text{s}$
- c (Speed of light) $\approx 3 \times 10^{8}\ \text{m/s}$

$$f = \frac{c}{\lambda}$$

As we know, the speed of light is c = 3×10^8

$$R = \frac{0.70 \times 1.6 \times 10^{-19} \times 1310}{6.626 \times 10^{-34} \times 3 \times 1}$$

$$R \approx \mathbf{0.739}\ \text{A/W}$$

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2. Calculating Photocurrent (I_p):

The formula relating current to power is:

$$I_p = R \times P_{in}$$

Where:

- P_{in} (Optical Power) = $5\mu\text{W} = 5 \times 10^{-6}\ \text{W}$

$$I_p = 0.739 \times 5 \times 10^{-6}$$

$$I_p = 3.695 \times 10^{-6}\ \text{A} = \mathbf{3.695\mu A}$$